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Potential impact assessment between SST and extreme precipitation: an observational study in Southeastern Brazil

This work aims to identify, by means of statistical analysis, the relationship between extreme precipitation events and SST anomalies (SSTA) in the municipalities surrounding the Ilha Grande (IGB) and Sepetiba (SB) bays in the state of Rio de Janeiro evaluating its annual distributions using measured data from rainfall stations and relating these events to potential SST anomalies found in this region. Data from 10 rainfall stations distributed around the bays and SST dataset obtained from the Multi-scale Ultra-high Resolution Sea Surface Temperature (MUR) from 2003 to 2014 were used. SSTA and their average were generated for each of the three subareas delimited in the study area. The obtained time series of each subarea define the thresholds for significant SSTA, based on their respective standard deviation. The number of days with SSTA were obtained from these significant anomaly values, and days with positive or negative SSTA, for each subarea, were computed. For SSTA analysis, only events with significant anomalies were considered. Only SSTA occurring on the days of intense precipitation highlighted in P95 and up to 3 days before the extreme event date were analyzed. The results had shown that about 35% of extreme precipitation events were potentially related to the presence of significant SST anomalies in the studied area. Finally, it is pointed that regional anomalies in SST, such as those described in this study, can also contribute to the formation of extreme rain events.

Keywords: Extremes of precipitation; Sea Surface Temperature; Ilha Grande Bay; Sepetiba Bay.

Avaliação do impacto potencial entre TSM e precipitação extrema: um estudo observacional no sudeste do Brasil

Este trabalho tem como objetivo identificar, por meio de análise estatística, a relação entre eventos extremos de precipitação e anomalias de TSM (ATSM) nos municípios do entorno das baías da Ilha Grande (IGB) e Sepetiba (SB) no estado do Rio de Janeiro. Avaliando sua distribuições, usando dados medidos de estações pluviométricas e relacionando esses eventos a potenciais anomalias de TSM encontradas nesta região. Foram usados dados de 10 estações pluviométricas distribuídas ao redor das baías e o conjunto de dados de TSM obtidos do Multi-scale Ultra-high Resolution Sea Surface Temperature (MUR) de 2003 a 2014. A ATSM e sua média foram geradas para cada uma das três subáreas delimitadas na área de estudo. As séries temporais obtidas de cada subárea definem os limites para ATSM significativo, com base em seus respectivos desvios padrão. O número de dias com ATSM foi obtido a partir desses valores de anomalia significativos, e dias com ATSM positivo ou negativo, para cada subárea, foram computados. Para a análise de ATSM, apenas eventos com anomalias significativas foram considerados. Foram analisadas apenas as ATSM ocorridas nos dias de precipitação intensa acima do percentil 95 e até 3 dias antes da data do evento extremo. Os resultados mostraram que cerca de 35% dos eventos extremos de precipitação foram potencialmente relacionados à presença de anomalias significativas de TSM na área estudada. Por fim, aponta-se que anomalias regionais na TSM, como as descritas neste estudo, também podem contribuir para a formação de chuvas extremas.

Palavras-chave: Extremos de precipitação; Temperatura da superfície do mar; Baía da Ilha Grande; Baía de Sepetiba.

Topic: **Meteorologia, Climatologia e Mudanças Climáticas**

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INTRODUCTION

Recent studies have correlated precipitation and sea surface temperature (SST), focusing on large and planetary-scale patterns. Diaz et al. (1998) described the relationship between SST patterns in the Atlantic and Pacific oceans with precipitation anomalies in Uruguay and southern Brazil. Other authors (LIMA et al., 2011; ROWELL, 2003; TOY et al., 2014) suggest that SST is related to extreme precipitation events. On Taiwan's southwestern coast, the temperature gradient in the northern sector of the South China Sea during the early summer monsoon is related to the intensification of rainfall during this period (TOY et al., 2014). In this same study, the authors show a rainfall reduction of 20%, based on numerical simulations with a smoothed SST gradient, and their results indicate a SST gradient impact on the rainfall intensification in this region.

In northeastern Brazil (NEB), it was found that positive SST anomaly on the Eastern Pacific (El Niño) and negative anomaly on the South Tropical Atlantic (during positive Atlantic dipole) impact the regional precipitation regimen solely. Besides, accentuated effects occur when these anomalies act together in-phase (NÓBREGA et al., 2016). Silva et al. (2011) state that anomalous warming in some regions of the Atlantic can cause extreme rain events on the east coast of the NEB.

The literature points to a large number of studies with large-scale applications (LIMA et al., 2011; ROWELL, 2003; TOY et al., 2014), some of those focus on mesoscale (TOY et al., 2014; SILVA et al., 2011; NÓBREGA et al., 2016). On the other hand, there is a lack of studies trying to correlate SST anomalies to microscale precipitation regimens.

In Brazil's southeast coast, a complex terrain characterizes the Ilha Grande (IGB) and Sepetiba (SB) bays region. These bays are located westward from Rio de Janeiro Metropolitan Area (RJMA) and include other municipalities (Itaguaí, Mangaratiba, Angra dos Reis, and Paraty) that characterized an area named Green Coast (Costa Verde) with an intense Touristic appeal (Figure 1). This area is historically affected by intense rainfall during the rainy season, leading to landslides, floodwaters, and loss of lives and properties (OGITA et al., 2019). Thus, studies related to extreme precipitation in these places are essential for managing events such as landslides and floods to plan preventive actions and reactions to severe/extreme events.

Therefore, this work aims to identify extreme precipitation events in the municipalities surrounding the IGB and SB bays in the state of Rio de Janeiro evaluating its annual distributions using measured data from rainfall stations and relating these events to potential SST anomalies found in this region. This work is essentially observational, focused on measured SST and precipitation data.

METHODOLOGY

The study area and rainfall stations (Figure 1) are located between 23.35º and 22.71º S and 044.75º and 043.14º W, comprising five municipalities on Rio de Janeiro state, as described before. Figure 1a shows the whole study area, and figure 1b illustrates the two bays and the location of the pluviometers (stations). Station 1 (Rio de Janeiro) and 2 (Marambaia) are located in Rio de Janeiro's municipality. The station 3

(Coroa Grande) location is at Itaguaí, and station 4 location is at Mangaratiba. The stations 5 (Bracuí), 6 (Vila Mambucaba) and 7 (Vila Perequê) are located at Angra dos Reis and stations 8 (São Roque), 9 (Parati), and 10 (Patrimônio) are located at Paraty.

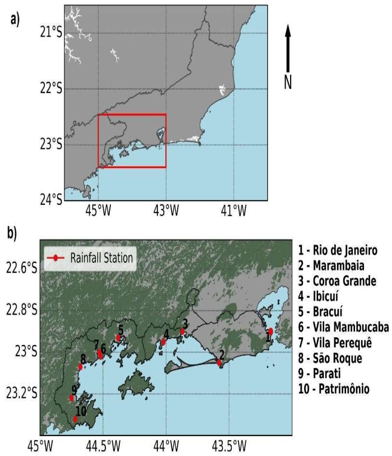

Figure 1: Study area and location of rainfall stations

To better understand the potential local impact of SST on the rainfall regimen of the region, the study area was divided into three subareas (Figure 2). The region comprising the area of IGB and SB corresponds respectively to Ilha Grande and Sepetiba bays. The area called SEA corresponds to the outer portion of the bays, closer to the oceanic influence. The SST anomalies data were extracted from these areas (IGB, SB, and SEA).

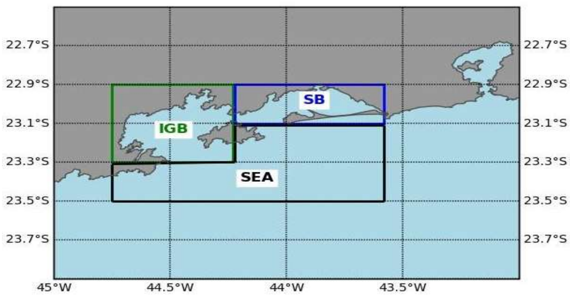

Figure 2: Subareas of the study area named: IGB, SB, and SEA

Rainfall data

Precipitation data were extracted from the National Water Agency (ANA), through the stations located at the cities of Parati, Angra dos Reis, Mangaratiba and Itaguaí and by the National Institute of Meteorology (INMET), through automatic weather stations in the municipality of Rio de Janeiro for the period 2003 to 2014. A total of eight (8) ANA stations and two INMET stations were used, which distribution in the study area is predominantly around the bays (Figure 1b).

SST data

SST dataset was obtained from the *Multi-scale Ultra-high Resolution Sea Surface Temperature* (MUR) from 2003 to 2014, consisting of daily global analysis of SST, with a horizontal resolution of 1km. MUR is an SST product generated from radiometric data collected in the spectral region of thermal infrared and microwave. The SST data provided corresponds to an estimative of the foundation temperature; that is, the temperature of the water column disregarding the daytime temperature variations (DONLON et al., 2007), representing, therefore, the temperature of the mixing layer. In this study, daily data were extracted from the MUR basis to evaluate potential relationships between SST daily anomalies and the rain intensity registered over the selected area.

SST anomaly

By subtracting the daily SST data values from the SST average obtained for the whole period of MUR availability, for each of the three subareas, the SST anomalies (SSTA) were generated. From these SSTA values, the average values were calculated for each of the three subareas in the same analyzed interval of the precipitation data. The obtained time series of each subarea define the thresholds for significant SST anomalies, based on their respective standard deviation. The number of days with SSTA was obtained from these significant anomaly values, and days with positive or negative SSTA, for each subarea, were computed.

For SSTA analysis, only anomalous events were considered, those with significant anomalies for each subarea. Significant anomalies were defined as mean values above and below one standard deviation around the mean SST. Only SSTA occurring on the days of intense precipitation highlighted in P95 and up to 3 days before the extreme event date were analyzed. By considering the MUR SST availability (from 2002 on) and rainfall datasets, the period from 2003 to 2014 was analyzed. Additionally, the use of this twelve-year interval guarantees continuous and concomitant data, providing a long enough time series for this study's purposes.

Precipitation extremes

According to the World Meteorological Organization (WMO) guide, an extreme event is defined as the occurrence of a climatological variable above or below a threshold value near the upper or lower extremes of the observed value range (WMO, 2015). As there is a wide variation in global rainfall patterns, it is not possible to establish a definition of intense rainfall that satisfies all regions.

Extreme rain events are those in which a measured limit value is exceeded and which cause specific impacts or are considered extreme due to their rarity (WMO, 2015). The extreme precipitation events considered rare are those with percentiles greater than 90, 95, or 99. There is no homogeneous distribution of extreme precipitation events since regional and seasonal exist (WMO, 2015). Thus, in order to obtain a general and consistent guide to the study of extreme precipitation, that might be relevant to adopt some parameters: magnitude, duration, severity, and spatial extent affected. As this study considers a regionalized area and dataset, the duration of 24 hours recommended by the WMO was used.

Days of intense precipitation, or extreme precipitation events, can be considered those in which the daily precipitation exceeded the 95th percentile (P95) calculated for each rainfall measuring station (DERECZYNSKI et al., 2009). The cases considered in this study were those in which more than half of the 10 pluviometers; that is, 6 or more stations recorded daily accumulated rain higher than P95, calculated for each point of rain measurement. A slightly different approach using only the events recorded in one rainfall station that registered the highest number of extreme events in the region was tested. Although the inference in the pluviometer that records the highest amount of rainfall produces a more significant number of extreme precipitation events, the results obtained with this approach were very similar and will not be detailed.

RESULTS AND DISCUSSION

The number of extreme events registered simultaneously on the pluviometers is shown in figure 3. A total of 1034 extreme events were recorded which 73 events occurred in 6, 7, 8, 9, or 10 rain stations simultaneously.

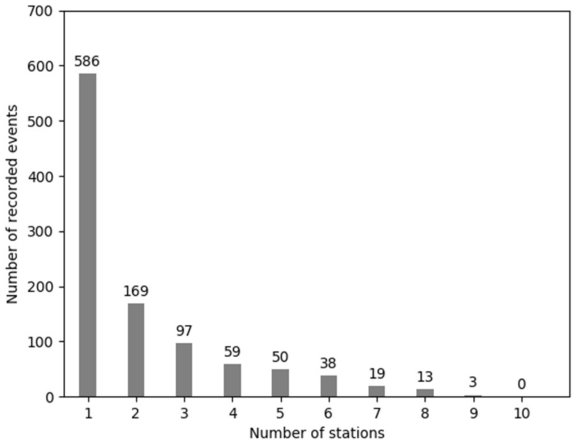

Figure 3: Number of extreme events recorded simultaneously in rainfall stations.

The annual distribution of the 73 extreme events from 2003 to 2014 is shown in figure 4. The years of 2004 and 2005 registered more extreme events throughout the period (10 events), followed by 2008 and 2010, where eight (8) events were recorded. In 2014, no extreme events were recorded. This fact is associated with the intense drought that profoundly affected parts of the southeastern region in Brazil. (COELHO et al., 2016).

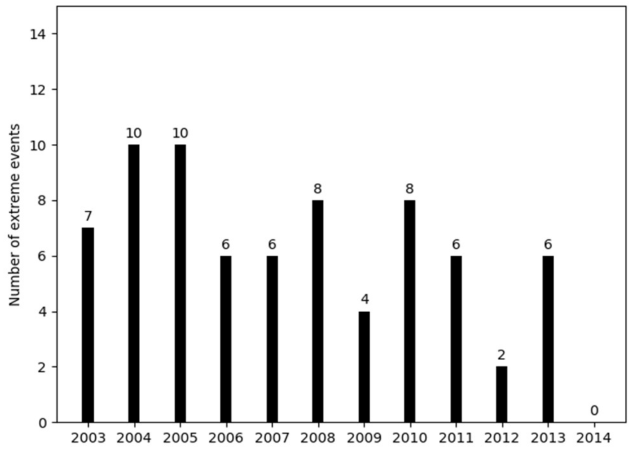

Figure 4: Annual distribution of extreme events.

Figure 5 shows the distribution of the 73 extreme events by season. It is possible to observe a higher frequency of extreme events in summer and spring during the wet season. On the other hand, there is a low frequency of such events during autumn and winter, the dry season (ANDRÉ et al., 2008).

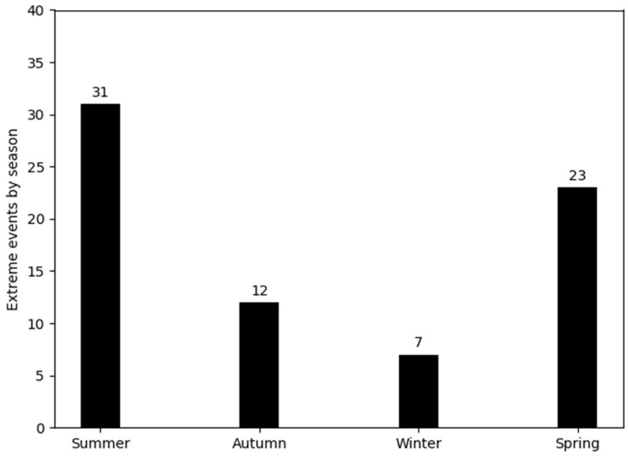

Figure 5: Distribution of extreme events by season.

Figures 6, 7, and 8 show the SSTA time series, as well as the means and standard deviations for the IGB, SB, and SEA areas, respectively. The standard deviation was used to define significant SST anomalies. The threshold for a significant anomaly in IGB and SB areas were determined by values above 1.20°C and below -1.20ºC. For the SEA area, the significant anomalies were that above 1.12ºC and below -1.12ºC. These values were calculated from the available dataset and are valid for the time series used in this study.

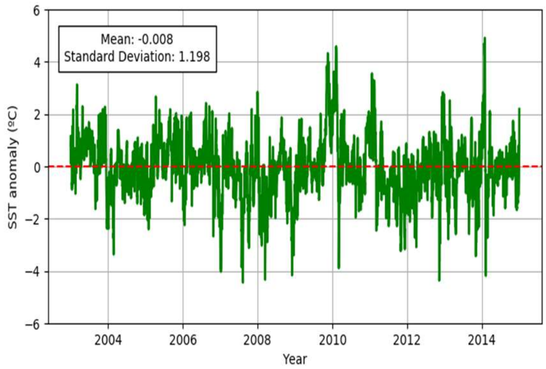

Figure 6: SSTA time series on extreme event days in IGB area.

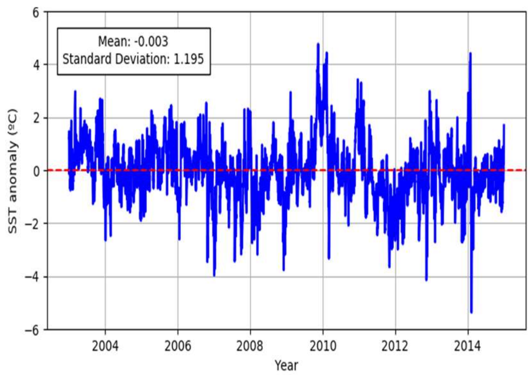

Figure 7: SSTA time series on extreme event days in SB area.

From the values obtained from the data time series, the number of days that recorded SSTA in each region was determined (IGB, SB, and SEA) (Figure 9), considering the 73 extreme events. This analysis considered the SSTA on extreme event day, as well as the three days before the event.

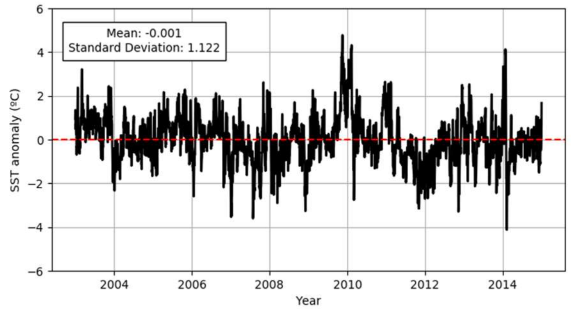

Figure 8: SSTA time series on the days of the extreme event at the SEA area.

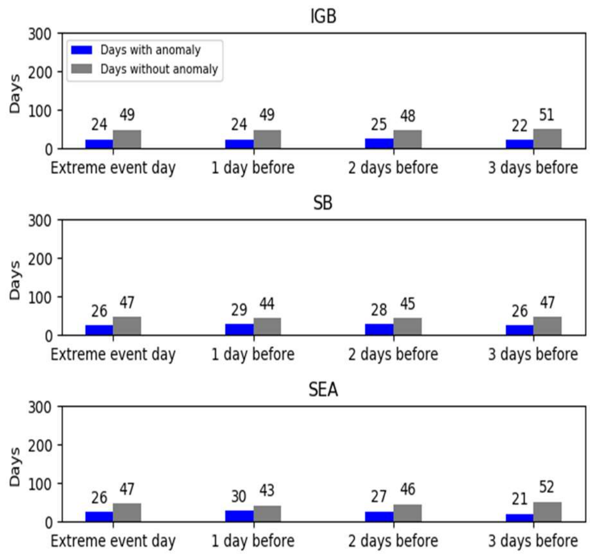

Figure 9: Number of days with or without SSTA in IGB, SB, and SEA areas.

It can be observed that, for all regions and dates considered, the number of days without SSTA is always higher than the ones with the anomaly, indicating the regularity of the used dataset (TRENBERTH, 1997; ZHAO et al., 2012). The days with SSTA are present in about 35% of extreme events, indicating a relevant percentage and potential SSTA influence on such severe events. By considering the day of the extreme event and the previous three days, the results indicate that more days with SSTA were recorded in SB (109 days with SSTA), followed by SEA (104 days with SSTA) and IGB (95 days with anomaly).

Regarding the days with positive or negative SSTA were analyzed (Figure 10). In this case, in almost all regions (except for SSTA one day before the extreme event in IGB), there was a predominance of positive anomalies in the three days before the extreme event, but with negative anomalies dominating on the extreme event day. Possibly, days before the event with positive SSTA, induce the atmosphere gain of heat and humidity, which can contribute to the intensification of the rains in this region.

From the results, the potential local influence of SSTA in the municipalities precipitation regimen of the surrounding the IGB and SB was evaluated, especially in situations of extreme events, as detailed in this study. The percentage of 35% of extreme events occurring on days with recorded significant SSTA might support this hypothesis. As mentioned in section 2, this result was also evaluated with a slightly different approach, addressing only the events recorded in one rainfall station (i.e., with a higher sample rate – 586 events) and, very similarly, 30% of the extreme events occurred on days with significant SSTA.

The results shown here might point to the potential importance of SST in predicting extreme precipitation events in small scale and could indicate the need to reevaluate the ways of assimilating SST in the weather forecast models, especially where complex terrain and land use areas prevail, such as IGB and SB. The fact of 35% of the total events of severe rainfall registered in a time series of 11 years could be a sign that SST small scale anomalies are one of the physical components that trigger severe events, such as the orography rains, which is very common in that area (SILVA et al., 2014; FARIAS et al., 2019)

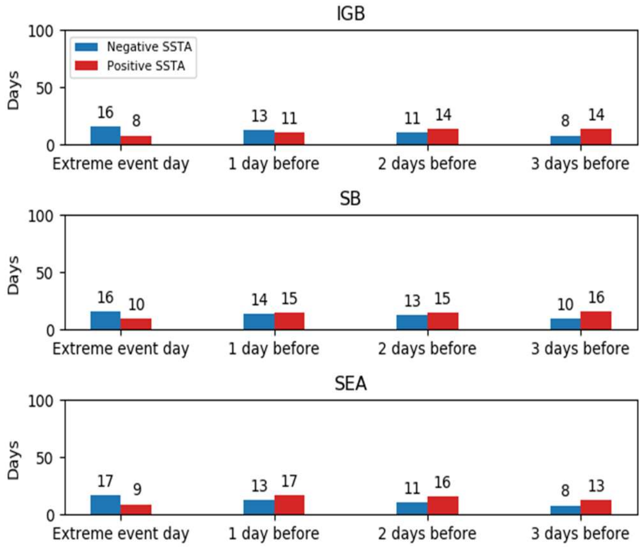

Figure 10: Days with positive or negative SSTA in IGB, SB, and SEA subareas

Although it cannot be stated that there is a direct relationship between El-Niño and La-Niña events and precipitation in the southeastern region, concerning extreme events, more specifically, Grimm et al.(2009) found changes in the frequency and intensity of extreme events in southeastern South America in El-Niño or La-Niña years. In this study, there is also a change in the frequency of extreme events occurring in El-Niño or La-Niña years. Table I illustrates the years of El-Niño and La-Niña events occurrence, as well as the intensity of such (severe) events each year.

Table 1: - Years of occurrence of El Niño or La Niña events (NOAA).

Years of occurrence of El Niño or La Niña	NOAA Classification
2002-2003	El Niño moderate
2004-2005	El Niño weak
2005-2006	La Niña weak
2006-2007	El Niño weak
2007-2008	La Niña intense
2008-2009	La Niña weak
2009-2010	El Niño moderate
2010-2011	La Niña intense
2011-2012	La Niña moderate
2014-2015	El Niño weak

Although a direct relationship between southern oscillation and local precipitation regimen is tough to link (MARENGO et al., 2005; KAYANO et al., 2007), it was possible to identify that in the first intense La-Niña event of Table I, occurred in 2007 and 2008, a high number of extreme events (8 events) were observed in 2008. During the second intense La-Niña event in 2010-2011, 8 extreme events were recorded in 2010 and 6 in 2011. It is also possible to notice that no extreme event was recorded in 2014, a weak El

Niño year with anomalous atmospheric conditions. In addition to this El Niño event, 2014 also faced an intense atmospheric blocking (RODRIGUES et al., 2017), causing an intense drought in Southeastern Brazil (NOBRE et al., 2016) and increasing SST (DOTTORI et al., 2015). This episode occurred in 2014, generated a negative precipitation anomaly considered record (COELHO et al., 2016), which corroborates the absence of extreme events found in this paper's results.

CONCLUSION

This work investigated the potential relationship of SSTA of coastal bays with extreme precipitation events that occurred in rainfall stations on the coast, near the bays of Ilha Grande and Sepetiba reasoned on measured rainfall data and estimated data from MUR SST, performing an observational inference of this SSTA – extreme precipitation link. For this, three subareas were delimited to calculate the SST anomalies that occurred on extreme event day and in the three days preceding it.

Generally, the methodology adopted in this study to evaluate the extreme precipitation events and SSTA provided results in agreement with typical seasonal patterns known in the region. Also, the boundaries found to classify what is severe and how big the anomalies are were based on observational data. Concerning extreme events, the years of 2004 and 2005 recorded show the highest number of events. Furthermore, the smallest extreme event number was in 2014 due to the severe drought that occurred in this region (NOBRE et al., 2016).

About 35% of extreme precipitation events were related to the presence of significant SST anomalies in the studied area. It is possible to observe a pattern of positive anomalies, especially in the three days preceding the extreme event, which inverts to a negative anomaly on the event's day. Another finding is that there was no significant difference between the SSTA areas (BIG, BS, and MAR), which can be considered a single area in future studies. This fact reinforces the idea that the SSTA is not the only factor that influences the amount of precipitation but is one of them, and their level of importance depends on the action of other factors operating in the area at the time of passage of the event.

Preliminary, thus, as Grimm et al. (2009), it is possible to notice changes in the frequency of occurrence of extreme precipitation events associated with El-Niño and La-Niña events since there are more records of extreme events in La-Niña intense years.

Finally, it is pointed that not only in the Pacific or other areas of the Atlantic may be related to extreme rain events, because regional anomalies, such as those described in this study, can also contribute to the formation of these events.

It is also considered that this study might allow an inference for a potential indication of a new SST data assimilation form on operational tasks of weather and climate forecast models. Thus, the evaluation of the mean regimes of SST and its anomalies, applied to these bays, may be necessary better to understand the rainfall regime in the local region.

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